THE EVOLUTION OF THE CELL. III

BY THE LATE PROFESSOR E. A. MINCHIN, F.R.S.

In the phase of evolution that I have termed the pseudomoneral or cytodal phase, in which the organism was a droplet of periplasm containing scattered biococci or chromidiosomes, metabolism would result in an increase in the size of the cytode-body as a whole, accompanied by multiplication of the chromidiosomes. Individualization of the cytodes would tend to the acquisition of a specific size, that is to say, to a limitation of the growth, with the result that when certain maximum dimensions were attained the whole cytode would divide into two or more smaller masses amongst which the chromidiosomes would be partitioned.

In the next stage of evolution, the protocyte with a definite nucleus, it is highly probable that at each division of the cell-body, whether into two or more parts, the primitive method of division of the nucleus was that which I have termed elsewhere "chromidial fragmentation";[26] that is to say, the nucleus broke up and became resolved into a clump of chromidiosomes, which separated into daughter-clumps from which the daughter-nuclei were reconstituted. Instances of nuclear divisions by chromidial fragmentation are of common occurrence among the Protozoa and represent probably the most primitive and direct mode of nuclear division.

It is clear, however, that if the chromatin-grains are to be credited with specific individuality and qualitative differences amongst themselves, this method of nuclear division presents grave imperfections and disadvantages, since even the quantitative partition of the chromatin is inexact, while the qualitative partition is entirely fortuitious. Chromidiosomes having certain specific properties might all become accumulated in one daughter-cell,

[26] *Op. cit.*, p. 101.

and those having opposite properties in the other, so that the two daughter-cells would then differ entirely in their properties.

I can but refer briefly here in passing to the interesting theory put forward by Bütschli, to the effect that sexual phenomena owe their first origin to differences between cellular organisms resulting from the imperfections of the primitive methods of cell-division. If we assume, for instance, as so many have done, that one of the earliest qualitative differences between different chromatin-granules was that while some influenced more especially the trophic activities of the cell, others were concerned specially with kinetic functions; then it might easily happen, after nuclear division by chromidial fragmentation, that all, or the majority of, the kinetic elements pass into one of the two daughter-cells, while its twin-sister obtains an undue preponderance of trophic chromatin. As a consequence, some cells would show strong kinetic but feeble trophic energies and others the opposite condition, and in either case the viability of the cells would be considerably impaired, perhaps inhibited. If it be further assumed that cells of opposite tendencies, kinetic and trophic, attract one another, it is easy to see that the union and fusion of two such cells, the one unduly kinetic (male) in character, the other with a corresponding trophic (female) bias, would restore equilibrium and produce a normal cell with kinetic and trophic functions equally balanced. On this view, sexual union, at its first appearance, was a natural remedy for the disadvantages arising from imperfect methods of nuclear division.

It is not surprising, therefore, to find that the process of nuclear division undergoes a progressive elaboration of mechanism which has the result of ensuring that the twin sister-granules of chromatin produced by division of a single granule shall be distributed between the two daughter-cells, so that for every chromatin-grain obtained by one daughter-cell an exact counterpart is obtained by the other; in other words, of ensuring an exact qualita-

tive, as well as quantitative, partition of the chromatin-particles. In its perfect form this type of nuclear division is known as karyokinesis or mitosis, and all stages in its progressive development are to be found in the Protozoa.

In the evolution of nuclear division by karyokinesis two distinct processes are being developed and perfected in a parallel manner, but more or less independently; first, the method of the partition and distribution of the chromatin-grains between the two daughter-nuclei; secondly, the mechanism whereby the actual division of the nucleus and the separation of the two daughter-nuclei are effected in the cell-division. I have dealt elsewhere[27] with the evolution of the mechanism of karyokinesis as exemplified by the numerous and varied types of the process found amongst the Protozoa, and I need not discuss the matter further here, but the behavior of the chromatin-grains may be dealt with briefly. The main feature in the process of the exact quantitative and qualitative distribution of the daughter-chromatin between the daughter-nuclei is the aggregation of the chromatin-grains or chromioles into definite, highly individualized structures known as chromosomes. In the most perfected forms of the process of chromosome-formation the chromioles become united into a linear series termed by Vejdovsky a chromoneme, which is supported upon a non-chromatinic basis or axis. According to Vejdovský, the supporting substance consists of linin; R. Hertwig, however, in his well-known studies on *Actinosphærium*[28] considers that the supporting and cementing substance of the chromosome is plastin derived from the substance of the nucleoli. However that may be, the essential feature of the chromosome is the cementing together of the chromioles to form the chromoneme, a thread of chromatin which may be disposed in various ways on the supporting axis, sometimes being wound spirally round it (Vejdovský).

[27] *Op. cit.*, pp. 105–120.
[28] *Abhandl. bayer. Akad.* (II. Cl.), XIX, 1898.

The actual division of the chromatin takes place by the longitudinal splitting of the chromoneme, in other words, by simultaneous division into two of each of the chromioles of which the thread is composed. In this way every chromiole which was contained in the original chromoneme is represented by a daughter-chromiole in each of the two daughter-chromonemes. It follows that the familiar process of the splitting of the chromosomes in karyokinesis is a mechanism which brings about in the most simple, sure and direct manner an exact quantitative and qualitative partition of the chromatin-grains between the two daughter-nuclei. In the sequel each daughter-nucleus is built up, according to Vejdovský, entirely and solely from one of the two daughter-clumps of chromosomes, and each chromosome is resolved again into its constituent chromioles, giving rise in some cases to a definite portion of the nucleus, a karyomere, from which again, at the next nuclear division, the chromosome is reconstituted by the chromioles falling into line in an orderly manner.

The chromatin-cycle of a cell in which the process of division by karyokinesis takes place in its most perfectly developed form, may, therefore, be conceived as follows: The nucleus in its resting state contains a definite number of companies or brigades of chromatinic units (chromioles), each brigade spread over a certain extent of the nuclear framework forming a karyomere. As a preparation to division each separate brigade of chromioles falls into line as the chromoneme, forming with its supporting substance the chromosome; there are formed, therefore, just so many chromosomes as there were karyomeres in the nucleus. In this disciplined and orderly array each chromiole undergoes its division into two daughter-chromioles, so that each file or chromoneme of chromioles splits into two files. At the reconstitution of the daughter-nuclei each daughter-chromosome gives rise to a karyomere again, the chromioles falling out of the ranks and disposing themselves in an apparently irregular manner on the

newly-built framework of the daughter-nucleus to constitute their own particular karyomere. Thus karyokinesis differs only from the most primitive method of division by chromidial fragmentation in that what was originally a haphazard method of distribution has become a disciplined and orderly manœuvre, performed with the precision of the parade-ground, but in a space far less than that of a nutshell.

In the nuclear division of Protozoa, without going into excessive detail, it may be stated broadly that all stages are to be found of the gradual evolution of the tactical problem which constitutes karyokinesis. The chromosomes in the more primitive types of nuclear division are usually very numerous, small, irregular in number and variable in size; the splitting of the chromosomes is often irregular and not always definitely longitudinal; and distinct karyomeres have not so far been recognized in the nuclei of Protozoa. In many cases only a part, if any, of the chromatin falls in to form the chromosomes, and a greater or less amount of it remains in the karyosome, which divides directly into two. The various types of nuclear division in Protozoa have been classified as promitosis, mesomitosis and metamitosis, for detailed accounts of which those interested must refer to the textbooks and original descriptions.

I have dealt briefly with the problem of the evolution of karyokinesis because the process of nuclear division is, in my opinion, of enormous importance in the general evolution of living organisms. I have expressed elsewhere[29] the opinion that the very existence of multicellular organisms composed of definite tissues is impossible until the process of karyokinesis has been established and perfected. For tissue-formation it is essential that all the cells which build up any given tissue should be similar, practically to the point of identity, in their qualities; and if it is the chromatin-elements of the cell which determine its qualities and behavior, then the exact qualitative

[29] *Op. cit.*, p. 120.

division of the chromatin, as effected in karyokinesis is indispensable as a preliminary to the production of identically-similar daughter-cells by division of a parent-cell. Hence it becomes intelligible why, amongst Metazoa, we find the occurrence of nuclear division by karyokinesis in its most perfect form to be the rule, and "direct" division of the nucleus to be the rare exception, while, on the other hand, in the Protista, and especially in the Protozoa, we find every possible stage in the gradual evolution of the exact partition of the chromatin in the process of nuclear division, from chromidial fragmentation or the most typical amitosis up to processes of karyokinesis as perfect as those of the Metazoa.

There now remains only one point of general interest in the evolution of the cell to which brief reference must be made, namely, the divergence of animal and vegetable cells. Not being a botanist, I desire to approach this question with all caution; but as a protozoologist it seems to me clearly indicated that the typical green plant-cell took origin amongst the Flagellata, in that some members of this group of Protozoa acquired the peculiar chromatophores which enabled them to abandon the holozoic or animal mode of life in exchange for a vegetative mode of nutrition by means of chlorophyll-corpuscles. It is well known that many of these creatures combine the possession of chlorophyll with an open, functional mouth and digestive vacuoles, and can live either in the manner of plants or of animals indifferently or as determined by circumstances. It would be interesting to know exactly what these chromatophores, at their first appearance, represent; whether they are true cell-organs, or whether, as some authorities have suggested, they originated as symbiotic intruding organisms, primitively independent. I do not feel competent to discuss this problem. I would only remark here, that if the green plant-cell first arose amongst the Flagellata, then the distinction between plant and animal (that is, green plant and animal) is not so fundamental a divergence in the series of living beings

as is popularly supposed, but is one which did not come into being until the evolution of organisms had reached a relatively advanced stage, that, namely, of the true nucleated cell.

I have confined myself in this address to the evolution of the cell as this organism is seen in its typical form in the bodies of the multicellular organisms, starting from the simplest conceivable type of living being, so far as present knowledge enables us to conceive it. But there is not the slightest reason to suppose that the evolution of the Protista took place only in the direction of the typical cell of the cytologist. Besides the main current leading up to the typical cell there were certainly other currents tending in other directions and leading to types of structure very unlike the cells composing the bodies of multicellular organisms. It is impossible that I should do more here than indicate some of the divergent lines of evolution, and I will confine myself to those seen in the Protozoa.

Taking as the starting-point and simplest condition in the Protozoa a simple cell or protocyte, in which the body consists of a small mass of cytoplasm containing a nucleus, with or without chromidia in addition, an early specialization of this must have been what I may term the plasmodial condition, typical of Rhizopods in which the cytoplasm increased enormously to form relatively large masses. The nucleus meanwhile either remains single and grows very large or, more usually, a great number of nuclei of moderate size are formed. From this large plasmodial type is to be derived the foraminiferal type, characterized by the creeping habit of life, and probably also the radiolarian type, specialized for the floating pelagic habit. Both foraminiferal and radiolarian types are characterized by an excessive development and elaboration of skeletal structures, and the geological record proves that these two types of organisms attained to a high degree of specialization and diversity

of form and structure at a very early period.[30] The Mycetozoa exemplify another development of the creeping plasmodial type adapted to a semi-terrestrial mode of life.

In the Mastigophora the body generally remains small, while developing organs of locomotion and food-capture in the form of the characteristic flagella. In this class there is a strong tendency to colony-formation brought about by incomplete separation of sister-individuals produced in the ordinary process of reproduction by binary fission. The so-called colonies (they would better be termed families) show a most significant tendency to individualization, often accompanied by physiological and morphological specialization of the component flagellate individuals.

As an offshoot, probably, from ancestors of the Mastigophoran type arose the Infusoria, the Ciliata and their allies, representing by far the most highly organized unicellular type of living being. No cell in the bodies of the Metazoa attains to such a complication of structure as that exhibited by many Ciliates. In the Metazoa the individual cells may be highly specialized for some particular function of life; but a Ciliate is a complete and independent organism and is specialized for each and all of the vital functions performed by the Metazoan body as a whole. From the physiological standpoint a Ciliate (or any other Protist) is equivalent and analogous to a complete Metazoon, say a man, but I can not for a moment agree with Dobell[31] that the body of a Ciliate is homologous with that of a Metazoon—not at least if the word homologous be used in its usual biological sense of homogenetic as opposed to homoplastic. Dobell appears to me to negative his own conclusion when he maintains that the body of a Ciliate is "non-cellular" while admitting that the Metazoon is multicellular; how then can they be said to be homologous? Only if the term homologous be

30 For Foraminifera see especially Heron-Allen, *Phil. Trans.* (B), Vol. 206 (1915), p. 229.

31 *Journal of Genetics*, IV (1914), p. 136.

used in a sense quite different from its ordinary significance.[32]

In addition to the highly developed structural differentiation of the body the Infusoria exhibit the extreme of specialization of the nuclear apparatus in that they possess, as a rule, two distinct kinds of nuclei, micronuclei and macronuclei, composed respectively of generative and trophic chromatin, as already pointed out. This feature is, however, but the culminating point in a process of functional specialization of the chromatin which can be observed in many Protozoa of other classes, and which, moreover, is not found invariably in its complete form in all Ciliata.

In this address I have set forth my conceptions of the nature of the simplest forms of life and of the course taken by the earliest stages of evolution, striving all through to treat the problem from a strictly objective standpoint, and avoiding as far as possible the purely speculative and metaphysical questions which beset like pitfalls the path of those who attack the problem of life and vitalism. I have, therefore, refrained as far as possible from discussing such indefinable abstractions as "living substance" or "life," phrases to which no clear meaning can be attached.

How far my personal ideas may correspond to objective truth I could not, of course, pretend to judge. It may be that the mental pictures which I have attempted to draw are to be assigned, on the most charitable interpretation, to the realm of poetry, as defined by the greatest of poets, rather than of science.

> The lunatic, the lover and the poet
> Are of imagination all compact;
>
> . . . .
>
> And as imagination bodies forth
> The forms of things unknown, the poet's pen
> Turns them to shapes and gives to airy nothings
> A local habitation and a name.

If I might be permitted to attempt an impartial criticism of my own scheme, I think it might be claimed that

32 See Appendix A.

the various forms and types of organisms in my evolutionary series, namely, the simple cell or protocyte, the cytode or pseudomoneral stage, the micrococcus, even the biococcus, are founded on concrete evidence and can be regarded as types actually existent in the present or past. On the other hand the *rôle* assigned by me to each type in the pageant of evolution is naturally open to dispute. For example, I agree with those who derive the Bacteria as primitive, truly non-cellular organisms, directly from the biococcus through an ancestral form, and not at all with those who would regard the Bacteria as degenerate or highly-specialized cells. But the crux of my scheme is the homology postulated between the biococcus and the chromatinic particle—chromidiosome or chromiole—of true cells. In support of this view, of which I am not the originator, I have set forth the reasons which have convinced me that the extraordinary powers and activities exhibited by the chromatin in ordinary cells are such as can only be explained on the hypothesis that the ultimate chromatinic units are to be regarded as independent living beings, as much so as the cells composing the bodies of multicellular organisms; and, so far as I am concerned, I must leave the matter to the judgment of my fellow-biologists.

I may point out in conclusion that general discussions of this kind may be useful in other ways than as attempts to discover truth or as a striving towards a verity which is indefinable and perhaps unattainable. Even if my scheme of evolution be but a midsummer-night's fantasy, I claim for it that it coordinates a number of isolated and scattered phenomena into an orderly, and, I think, intelligible sequence, and exhibits them in a relationship which at least enables the mind to obtain a perspective and comprehensive view of them. Rival theories will be more, or less, useful than mine, according as they succeed in correlating more, or fewer, of the accumulated data of experience. If in this address I succeed in arousing interest and reflection, and in stimulating inquiry and controversy, it will have fulfilled its purpose.

Appendix A.—The Cell-Theory

The most recent attack on the Cell-theory, as it is understood by the majority of modern biologists, has been made by Mr. Dobell, who, if I understand him rightly, refuses to admit any homology between the individual Protistan organism and a single cell of the many that build up the body of a Metazoon. On the contrary, he insists that the Protist is to be regarded as homologous with the Metazoan individual as a whole. On these grounds he objects to Protista being termed "unicellular" and insists that the term "non-cellular" should be applied to them.

As regards the cellular nature of the Protista, it is one of my aims in this address to show that amongst the Protista all stages of the evolution of the cell are to be found, from primitive forms in which the body can not be termed a cell without depriving the term "cell" of all definable meaning, up to forms of complex structure in which all the characteristic features of a true cell are fully developed. Thus in the Protozoa we find the protoplasmic body differentiated into nucleus and cytoplasm; the nucleus in many cases with a structure comparable in every detail to that of the nucleus of an ordinary body-cell in the Metazoa; reproduction taking place by division of the body after a karyokinetic nuclear division often quite as complicated as that seen in the cells of the Metazoa and entirely similar both in method and in detail; and in the sexual process of differentiation of the gametes on lines precisely similar to those universal in Metazoa, often just as pronounced, and preceded also in a great many cases by phenomena of chromatin-reduction comparable in principle, and even sometimes in detail, with the reduction-process occurring in Metazoa. I really feel at a loss to conceive what further criteria of homology between a Protozoon and a Metazoan cell could be demanded by even the most captious critic. On the ground of these and many other similarities in structure and behavior between the entire organism in the Protozoa and the individual cell, whether tissue-cell or germ-cell, in the Metazoa, the case

seems to me overwhelmingly convincing for regarding them as truly—that is to say, genetically—homologous.

Looking at the matter from another point of view, namely, from the standpoint of the Metazoa, it is true that in the groups of most complicated and highly organized structure the cells often develop secondary connections or fusions due to incomplete division, to such an extent that in parts of the body the individuality of the primitively distinct cells may be indicated only by the nuclei (as may occur also in Protozoa, for example, in associated gregarines); but in all Metazoa certain of the cells retain permanently their complete independence and freedom of movement and action. In the Metazoa possessing the simplest and most primitive types or organization, such as sponges and cœlenterates, the cells composing the body show far greater independence of action, and in the course of ontogeny entire groups of cells may alter their relative positions in the body as the result of migrations performed by individual cells; while it is now well known that if the adult sponge or hydroid be broken up completely into its constituent cells, those cells can come together again and build up, by their own individual activity, the regenerated body of the organism. For these reasons it seems to me impossible to regard the body-cells of the Metazoa otherwise than as individual organisms complete in themselves, primitively as independent as the individual Protozoon, and in every way comparable to it.

From the considerations summarized very briefly in the two foregoing paragraphs and capable of much greater amplification and elaboration, the view generally held that the entire organism of a Protozoon is truly homologous with a single body-cell of a Metazoon seems to me quite unassailable, and to have gained in force greatly from recent investigations upon both Protozoa and Metazoa. On the other hand, any Protist, as an organism physiologically complete in itself, is clearly analogous to the entire individual in the Metazoa—a comparison, however, which leaves the question of genetic homology quite untouched.

As regards the application of the term unicellular or non-cellular to the Protozoa, it is evident that if the evolution of living beings had never proceeded beyond the stage of the Protista, and if no multicellular organisms had ever been evolved, the term cell could then never have been invented by an intelligent being studying other living beings, supposing for an instant the possibility of such intelligence existing apart from a mammalian brain. So long as the Protozoa are studied entirely by themselves, without reference to any other forms of life, they may be termed non-cellular in the sense that they are not composed of cells. It is only when they are compared with multicellular organisms that the term unicellular becomes applicable on the ground of the homology already discussed between the Protozoon and the body-cell of the Metazoon.